Search for new physics at LHCb: rare decays of B hadrons and CP violation in the charm sector

M.-H. Schune

PROCEEDINGS OF SCIENCE

Search for new physics at LHCb: rare decays of B hadrons and CP violation in the charm sector

Marie-Hélène Schune *
Laboratoire de l'Accélérateur Linéaire Université Paris-Sud (Paris XI) et CNRS/IN2P3, France
E-mail: `schunem@lal.in2p3.fr`

on behalf of the LHCb collaboration

LHCb is an heavy flavour precision experiment with LHC at CERN. It will search for New Physics in CP violation and rare decays in the heavy quarks sector. The experiment is ready to take data for the soon expected start-up of the LHC. An overview of its physics program in both the rare decays of B hadrons and CP violation in the charm sectors is given, illustrated by few key examples: measurements of the $B_s \to \mu^+\mu^-$ and $B \to K^*\mu^+\mu^-$ decay modes, study of the photon helicity using the $B_s \to \phi\gamma$ and $B \to K^*e^+e^-$ decay modes, as well as search for CP violation using D^0 mesons

European Physical Society Europhysics Conference on High Energy Physics, EPS-HEP 2009,
July 16 - 22 2009
Krakow, Poland

*Speaker.

PoS(EPS-HEP 2009)186

1. Introduction

LHCb [1] is a dedicated b-physics experiment at the proton-proton LHC collider installed at CERN. It will benefit from the large $b\bar{b}$ cross section of $\sim 500\ \mu$b predicted at a centre-of-mass energy of 14 TeV[1] and from the $b\bar{b}$ pair production correlation in phase space. The LHCb detector is thus a single-arm forward spectrometer with an acceptance in polar angle between 15 and 300 mrad. About 45 % of the $b\bar{b}$ quarks are contained within its acceptance. In addition, it is also worthwile noting that different species of b-hadrons including baryons will be produced. A nominal year of data taking corresponds to an integrated luminosity of 2 fb^{-1}. Performances studies presented here are done fully simulating the detector response and including pile-up (multiple pp collisions in a single bunch-crossing) and spill-over (signal coming from particles produced in a previous bunch-crossing).

2. Search for $B_s \to \mu^+\mu^-$

The helicity suppressed $B_s \to \mu^+\mu^-$ decay is due to very rare loop diagram in the Standard Model (SM) and its Branching Ratio (BR) is expected to be extremely small : $(3.35 \pm 0.32) \times 10^{-9}$ [2] but New Physics (NP) models such as for example supersymmetry could enhance it up to 100 times. The best current limit is achieved by CDF : BR$< 4.7\ 10^{-8}$ at 90 % CL [3].

The LHCb experiment is well suited for studying this decay due to a high trigger efficiency, a good muon identification and an excellent invariant mass resolution. The analysis [5] is based on three variables: the $\mu^+\mu^-$ invariant mass, and two likelihood variables, one describing the particle identification information and the second one the geometrical information of the decay (impact parameter significance of the muons, B_s proper time, impact parameter of the B_s, distance of closest approach between the two muons, muon isolation). Likelihood function of these three variables will be calibrated on real data using control channels. The three dimensions space defined by these variables is divided in bins. The estimated background and the expected signal events for a given BR in each of these bins are used to compute the exclusion and discovery potential of the LHCb experiment [4]. The left-hand side plot of Figure 1 shows the BR[2] excluded at a Confidence Level (CL) of 90% CL as a function of the integrated luminosity up to 2 fb^{-1}. The luminosity needed for observing a signal with a 3σ significance for a given BR is shown on the right-hand side part of Figure 1. About 3 fb^{-1} are enough for a 3 σ evidence if the branching fraction is equal to the SM prediction. Any enhancement driven by NP will be observed sooner. With 10 fb^{-1}, a 5 σ discovery occurs if the branching fraction is at the level of the SM prediction.

3. Study of the $B \to K^*\mu^+\mu^-$ decay mode

Decays generated by the flavour-changing neutral current, such as $B \to K^*\mu^+\mu^-$ are also very interesting to probe NP. The diagrams contributing to this decay mode are shown in Figure 2. The Operator Product Expansion allows to parameterise the process in terms of an effective hamil-

[1] In the case of a center-of-mass energy of 8 TeV, the $b\bar{b}$ cross section is roughly divided by a factor 2.

[2] Since the number of B_s produced is not precisely known, the use of a normalisation channel with a well known branching fraction is required to obtain an absolute measurement of the branching fraction or an upper limit.

PoS(EPS-HEP 2009)186

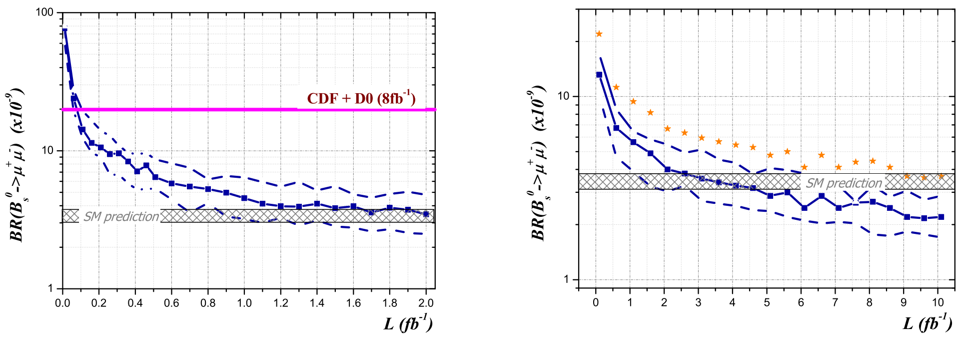

Figure 1: $B_s \to \mu^+\mu^-$ BR excluded (if no signal is present) at 90% CL (left) and observed at 3σ (right) as a function of the integrated luminosity. Dashed lines define the 90% probability region due to the limited MC statistics used to evaluate the expected background. Orange stars in the bottom plot indicate the luminosity needed for a 5σ discovery.

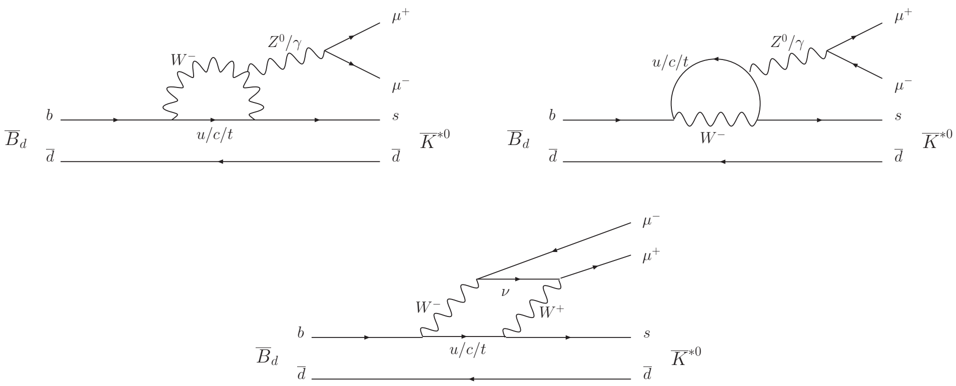

Figure 2: The Standard Model Feynman diagrams for the decay $B \to K^*\mu^+\mu^-$.

tonian :

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} [C_i(\mu) O_i(\mu) + C_i^{'}(\mu) O_i^{'}(\mu)] \tag{3.1}$$

where V_{tb} and V_{ts} are the numerically dominant CKM factors and, following the conventions of Ref. [6], primes (no primes) denote right-handed (left-handed) contributions. The local operators $O_i(\mu)$ describe the long range contributions to the decay while the Wilson coefficients $C_i(\mu)$ describe the short range contributions calculable perturbatively. The parameter μ is the renormalisation scale where the two quantities are matched and typically this is $\mathcal{O}(m_b)$. For the $B \to K^*\mu^+\mu^-$ decay mode the $i = 7, 9$ and 10 operators are the dominating ones (the right-handed ones are heavily suppressed). Among the observables which can be built, the Forward-Backward asymmetry $\mathrm{A_{FB}}$ in the $\mu^+\mu^-$ rest frame as a function of the $\mu^+\mu^-$ invariant mass is of interest, and in particular the invariant mass value, s_0, where $\mathrm{A_{FB}}$ crosses zero. The value s_0 can be precisely predicted by the SM and NP could give a sizeable deviation to this prediction. The position of s_0 depends on the values and signs of C_7, C_9 and C_{10}. Some first measurements have been conducted at B factories, but are statistically limited. LHCb is expected to collect 7200 events for 2 fb^{-1} with a background over signal ratio around 0.2; to be compared with the 450 events expected from the Belle and BABAR experiments together. By fitting a linear function to $A_{\rm FB}$ around the crossing region, a precision on s_0 of 0.46 GeV^2 with 2 fb^{-1} of data is forseen [8]. In addition, with large statistics, using the whole set of angular observables ($\cos\Theta_\ell$, $\cos\Theta_K$ and ϕ), LHCb can measure [7] the transversity amplitudes as a function of the dimuon mass [6]. The two crucial points for the study of the angular distributions of the decay products of the $B \to K^{*}\mu^+\mu^-$ decay mode are the understanding of the event acceptance as a function of the whole set of variables ($\cos\Theta_\ell$, $\cos\Theta_K$ and ϕ) and of the $\cos\Theta_\ell$, $\cos\Theta_K$ and ϕ distributions for the background.

4. Study of the photon helicity

The SM predicts a right-handed component in the photons generated by the $b \to s\gamma$ transitions to a level of $O(m_s/m_b)$. In several extensions of the SM, the photon can acquire an appreciable right-handed component due to chirality flip in the transition [9] with a small impact on the SM value of the branching ratio. One of the experimental technique to probe the photon helicity is via mixing-induced CP asymmetries [11]. The combination of the BELLE and BABAR measurements of the time dependent CP asymmetry using the $B \to (K_s^0\pi^0)\gamma$ decay mode [10] leads to an uncertainty of ~ 0.16 on the fraction of wrongly polarized photon. A similar study can be done using the $B_s \to \phi\gamma$ decay mode. For the B_s system the decay width difference between the two weak eigenstates, $\Delta\Gamma_s$, cannot be neglected in the proper time distribution. Therefore, for this measurement no flavour tagging is required and the time evolution of the $B_s \to \phi\gamma$ decay rare is given by :

$$\frac{d\Gamma(B_s \to \phi\gamma)}{dt} \propto e^{-\Gamma_s t}\left(\cosh\frac{\Delta\Gamma_s t}{2} - \sin 2\Psi \cos\phi_s \sinh\frac{\Delta\Gamma_s t}{2}\right) \tag{4.1}$$

where $\tan\Psi = \left|\frac{\overline{B}_s \to \phi\gamma_R}{\overline{B}_s \to \phi\gamma_L}\right|$ is the ratio of the decay amplitudes and $\cos\phi_s \sim 1$ in the SM. A signal sample of 11000 events for 2 fb^{-1} with a background over signal ratio smaller than 0.9 at 90% CL is expected [12]. This should allow to measure $\sin 2\Psi$ with a 20% statistical uncertainty. The crucial point of this analysis is to understand the proper time acceptance.

Another decay mode which would allow to test the photon helicity is the $B \to K^{*}e^+e^-$ decay mode. Compared to the $B \to K^*\mu^+\mu^-$ decay mode, it has a much better sensitivity to the photon polarization due to the small electron mass [13]. With a signal sample of about 200 events for an integrated luminosity of 2 fb^{-1} and a background over signal ratio of the order of 1, the expected statistical accuracy on the fraction of wrongly polarized photons is of the order of 0.1 [14]. This analysis is limited by the statistics.

5. CP violation in the charm sector

Along with the b physics trigger channels, a dedicated $D^{*} \to D^0(hh)\pi$ trigger will provide a high statistics charm sample – arising from both b decays and prompt production – which can be exploited in mixing and direct CP violation searches. In addition $D^{*} \to D^0(hhhh)\pi$ decays are also envisaged. The estimated $D^{*} \to D^0(hh)\pi$ yields to tape for an integrated luminosity of

Mode	Events to tape
$D^0 \to K^-\pi^+$	50 10^6
$D^0 \to K^-K^+$	5 10^6
$D^0 \to \pi^-\pi^+$	2 10^6
$D^0 \to K^+\pi^-$	0.2 10^6

Table 1: Number of $D^{*\pm}$ events from B decays for different D^0 channels for an integrated luminosity of 2 fb^{-1}.

2 fb^{-1} are given in Table 1. These come from b-hadron decays alone, similar numbers of events from prompt D^* are expected. These events can be used for example to search for CP violation. The CP asymmetry, $A_\Gamma(hh)$ is defined as :

$$A_\Gamma(hh) = \frac{\Gamma(D^0 \to hh) - \Gamma(\overline{D}^0 \to hh)}{\Gamma(D^0 \to hh) + \Gamma(\overline{D}^0 \to hh)} \tag{5.1}$$

where the D^0 ($\overline{D}^0$) initial flavour is tagged using the slow pion charge from the $D^{*\pm}$ decay and $h = K, \pi$. This asymmetry contains in principle direct and indirect CP violation. The presence of CP violation will be signed by a non-zero value of $A_\Gamma(hh)$. While the direct contribution is in general distinct for different final states, the indirect contribution is the same. The SM prediction for $A_\Gamma(hh)$ is at maximum of the order of 10^{-3} and values larger than 10^{-2} would be a clear sign of NP. The forseen LHCb statistical uncertainty on $A_\Gamma(KK)$ for an integrated luminosity of 2 fb^{-1} is 1.1×10^{-3} to be compared with the HFAG average [10]: $A_\Gamma(KK) = (-1.6 \pm 2.3) \times 10^{-3}$.

References

[1] The LHCb Collaboration, Journal of Instrumentation, 3 (2008) S08005.

[2] M. Blanke *et al.* TUM-HEP-626/06. JHEP 0610 (2006) 003, arXiv:hep-ph/0604057v5.

[3] The CDF Collaboration, Phys. Rev. Lett. **100**, 101802 (2008).

[4] A. L. Read, CERN Yellow Repport 2000-005.

[5] $B_s \to \mu^+\mu^-$ measurement : Roadmap document in preparation.

[6] F. Kruger and J. Matias, "Probing new physics via the transverse amplitudes of $B \to K^*\ell^+\ell^-$at large recoil", Phys. Rev. D**71** (2005) 094009.

[7] Ulrik Egede, 'Angular correlations in the $B \to K^*\mu^+\mu^-$decay', LHCb 2007-057

[8] $B \to K^*\mu^+\mu^-$ measurement : Roadmap document in preparation.

[9] R. N. Mohapatra and J. C. Pati, Phys. Rev. D 11 (1975) 566; G. Senjanovic and R. N. Mohapatra, Phys. Rev. D 12 (1975) 1502; G. Senjanovic, Nucl. Phys. B 153 (1979) 334; H. E. Haber and G. L. Kane, Phys. Rept. 117 (1985) 75.

[10] http://www.slac.stanford.edu/xorg/hfag/

[11] D. Atwood, M. Gronay and A. Soni, Phys. Rev. Lett. (1997) 15 [arXiv:hep-ph/9704272]

[12] $B_s \to \phi\gamma$ measurement : Roadmap document in preparation.

[13] Y. Grossman and D. Pirjol, J. High Energy Phys. 06 (2000) 029.

[14] $B \to K^* e^+ e^-$ Jacques Lefrançois and Marie-Hélène Schune, 'Measuring the photon polarization in $b \to s\gamma$ using the $B \to K^* e^+ e^-$ decay channel, LHCb 2009-008